Paola Ronzino

Q. CRMba: An ontological model for encoding buildings archaeology documentation

→ BIM, buildings archaeology, CIDOC CRM, CRMba, ontological extensions

The present work addresses the issues related to data interoperability in the field of buildings archaeology. It introduces the extension of the ontological model CIDOC CRM for buildings archaeology, namely CIDOC CRMba, which expresses the semantic relations between the building and its components with the introduction of specialized classes and properties, that allow to describe and document any information related to the built work throughout its life cycle. A first attempt to harmonize the ontological model for building archaeology documentation with the archaeological extension of the CIDOC CRM — CRMarchaeo — has been carried out with good results, and is presented in this work. Furthermore, the paper introduces the work carried out by the author (still in progress) to demonstrate how the integrated use of Building Information Modelling (BIM) and semantic technologies permits to connect different data sources and to combine them into a semantic network — allowing to have a unique representation of the building and its context — by exploring the integration of the CIDOC CRM ontology and its archaeological extensions with 3D models and the collected information.

Q.1 Introduction

An important aspect of the archaeological investigation is the study and documentation of standing archaeological structures. Buildings Archaeology is by far the oldest form of archaeology, having its origins in the Italian Renaissance. The actual name was decided during a conference of the Building Special Interest Group of the Institute of Field Archaeologist (1993). [01] Before then, the name used to identify the buildings archaeologists was building recorders, architectural archaeologists, or archaeological surveyors. [02]

Within this science, buildings are almost used as physical documents in their own right, providing examples of the development of decorative carvings, mouldings or plan forms, being the result of a series of modifications due to construction and destruction activities that modified their appearance over the historical periods.

The identification of these processes, the analysis of the different techniques and the materials used over its existence, provide archaeologists with an understanding of the continuity and discontinuity of the events that interested the built structure.

This information can be used to produce a detailed understanding of the development of any building, whether standing or in ruins, or when dealing with unconnected built structures found in stratified contexts.

The documentation produced during an archaeological investigation, consisting of the archaeologist's excavation diaries, notes, photos, maps, is then recorded into forms developed by archaeological institutions and research centres to preserve the evidences destroyed in the excavation process or collected during the observation of a standing structure. This information is usually archived into digital repositories and other information systems, which are frequently not readily available online or easy to find.

The implementation of an ontological model that helps to understand the life cycle of ancient buildings comes from the archaeologists' urgent need to avail themselves of a tool to support the archaeological investigation and its related activities, and to formalize the information gathered during observation and excavation.

So far, national standards have partly managed to give a more consistent systematization to archaeological excavation and investigation documentation by developing national-based guidelines and schemas. [03] Nevertheless, it is still possible to see extensive fragmentation and discrepancies between the various standards used by archaeological schools and the high-level systems developed by governments and other official institutions, which require a tool capable of managing the documentation and activities of the whole excavation process by using an adequate semantic framework.

The idea of developing archaeological extensions of the CIDOC CRM [04] ontology to cover the specific needs of an archaeological investigation and to help archaeologists examine and understand the complex relationships between all entities and activities related to it, derived from this need.

■ 01
Jason Wood, Buildings Archaeology: Applications in practice (ME-PRAC), Oxford 2004.

■ 02
Richard Morriss, The Archaeology of Buildings, Stroud 2004.

■ 03
Paola Ronzino, Nicola Amico, Franco Niccolucci, Assessment and comparison of metadata schemas for architectural heritage, in: CIPA Symposium, Prague 2011, http://www.conferencepartners.cz/cipa/proceedings/index.htm, version: 12–16 September 2011.

■ 04
CIDOC CRM. Current Official Version of the CIDOC Conceptual Reference Model, http://old.cidoc-crm.org/docs/cidoc_crm_version_6.2.2%20(WorkingDoc).pdf.

The two archaeological extensions of the CIDOC CRM, CRMba [05] designed to model the complexity of a built structure from the perspective of buildings archaeology, and the CRMarchaeo [06] developed to model the processes involved in the investigation of subsurface archaeological deposits, were implemented in the framework of the ARIADNE project. [07] The project addressed the issue of data fragmentation with the ultimate goal to enable the integration of archaeological datasets, providing an infrastructure for the exploration of the available archaeological dataset archives and the semantic integration of the digital resources made available within the network. ARIADNE adopted the CIDOC CRM ontology for the whole infrastructure.

■ 05
Paola Ronzino, CIDOC CRMba A CRM Extension for buildings archaeology information modelling, (Unpublished doctoral thesis). The Cyprus Institute, Nicosia, Cyprus 2015 and Paola Ronzino, Franco Niccolucci, Achille Felicetti, Martin Doerr, CRMba a CRM extension for the documentation of standing buildings, in: International Journal on Digital Libraries, 17 (1) 2016, pp. 71–78.

■ 06
CRMarchaeo, http://www.ics.forth.gr/isl/CRMext/CRMarchaeo/docs/CRMarchaeo_v1.4.pdf.

■ 07
Franco Niccolucci, Julian Richards, ARIADNE Advanced Research Infrastructure for Archaeological Dataset Networking in Europe, in: International Journal of Human-Computer Studies Art 7(1–2), 7088, 2013.

Q.2 The CRMba ontological model

The CRMba is an extension of the CIDOC CRM formal ontology, conceived to encode metadata about the documentation of archaeological buildings and to formalize the observation and analysis of the traces left on standing buildings by the activities performed on the monuments through time. The model was implemented to support the archaeological and architectural investigation methods used to phase and date the fabric and to support the analysis, interpretation, restoration and virtual reconstruction of archaeological standing buildings through the semantic encoding of the information, thus identifying the evolution of the structure over time and recording the relationships between each of the building components and with the building as a whole.

Furthermore, the CRMba model was developed with the aim of expressing the semantic relations of the stratigraphic units of standing buildings, taking into account the stratigraphic analysis theory of standing buildings [08], which is basically driven by the same principles of archaeological stratigraphy. [09]

After an accurate analysis of specific metadata standards and schemas developed to document the built heritage, the results of a cross-walk mapping between the main schemas and standards in use by national bodies at European level [10] demonstrated that such standards, although very rich in their structure, fail to describe the completeness of information about the building [T1].

In particular, the possibility to make explicit the parthood relations between components and the whole building, and the relationships between Stratigraphic Units amongst each other has not been explored yet. The result of the mapping enabled the identification of the hidden semantics and the inter-relationships of the metadata sets and highlighted the need to add more specialized concepts to the CIDOC CRM core ontology to describe the very complex structure of the buildings, especially as concerns the analytical description of the asset (static and functional components) and the relationship among its parts.

CRMba takes into consideration not only the physical layout of the archaeological stratification visible on the built structures, but also enables to register the events that led to the genesis of a particular stratification, allowing to record and subsequently to interpret the stratifications of the architectural remains found during an excavation.

The peculiarity of CRMba is that it focuses on the theory of parthood (Mereology) [11], and part-whole relation combined with topology (Mereotopology) [12] between the constituent parts and the whole structure, and introduces the concepts of **empty spaces** and **space functions** defined by form. [13]

■ 08
Richard Morriss, The Archaeology of Buildings, Stroud 2004 and Manfred Schuller, Building Archaeology, Icomos, Munich 2002 and Gian Pietro Brogiolo, Archeologia dell'edilizia storica, Como 1988 and Roberto Parenti, Archeologia dell'architettura, in: Dizionario di Archeologia. Temi, concetti e metodi, 2009, p. 39–43.

■ 09
Edward Harris, Principles of Archaeological Stratigraphy, London 1989 and Andrea Carandini, Storie della Terra. Manuale di scavo archeologico, Einaudi, Torino 1991.

■ 10
Paola Ronzino, Nicola Amico, Franco Niccolucci, Assessment and comparison of metadata schemas for architectural heritage, in: CIPA Symposium, Prague 2011, http://www.conferencepartners.cz/cipa/proceedings/index.htm.

■ 11
C. Maria Keet, Alessandro Artale, Representing and reasoning over a taxonomy of part-whole relations, in: Applied Ontology — Ontological Foundations of Conceptual Modelling, 3(1–2) 2008, pp. 91–110 and Achille Varzi, Mereology, Stanford 2014, http://plato.stanford.edu/entries/mereology/.

■ 12
Anthony G. Cohn, Achille C. Varzi, Connection Relations in Mereotopology, in: H. Prade (Hg.), European Conference on Artificial Intelligence (ECAI), John Wiley & Sons, Ltd, 1998, p. 150–154, http://www.columbia.edu/~av72/papers/Ecai_1998.pdf.

■ 13
Paola Ronzino, CIDOC CRMba A CRM Extension for buildings archaeology information modelling, (Unpublished doctoral thesis).

Category	**EU-Chic**	**MA / CA**	**MIDAS**	**Carare/ 3D Icons**
Asset ID	Unique reference number of asset	Codice Univoco	Primary Reference number	ID
Heritage Asset	→ Type of Heritage asset → name of Heritage Asset	→ Definizione tipologica → Denominazione	→ Monument Type → Material → Heritage Asset Name → Artifact Name Type	→ HA / Chrac-ters / heritage Asset type → HA / Appelation / name → HA / Characters / heritage asset type
Structure	Structural material: → Foundation → Wall / pillars → Interstore structure → Roof Finishing material: → Foundation → Wall / pillars → Interstore structure → Roof	→ Spazi / subdivizioni interna → Impianto strutturale → PiantaFondazioni → Strutture verticali → Strutture orizontamento → Copertura → Scale → Pavimenti i pavimentazioni → Elementi decorativi	→ Evidence → Representation Source → Construction Method → Material → Material Component → Note → Material Name → Associated Goods	→ HA / description → HA / construc-tion method → HA / Characters / materials
Conservation/ Restoration	→ Current physical condition → General condition → Condition of critical elements → Major Risks → long-term enviromental impact → sudden enviromental impact → Anthropogenic impact	→ Stato di conservazione → Riferimento alla parte → indicazioni specifiche	→ Modification State → Condition → Condition Statement → Completeness → Condition Date → Agent of Damage → Vulnerabality Level → Buffer Zone Width Enviromental	→ HA / Condtion / condition → HA / Condtions / Condition assessment → HA / Condtions / Condition date → HA / Condtions / relations

☐ T1
This table shows part of the cross-walk mapping of built heritage standards.

The model was developed in line with the theories and guidelines for the study of archaeological standing buildings developed by scholars like Brogiolo [14], Parenti [15], Schuller [16], Morriss [17], Davies [18] and by taking into account the real needs of the archaeological documentation of the standing structures expressed by national and international standards, as explained above [19]. The model reuses parts of the CIDOC CRM classes and properties, and refers to other CRM extensions such as CRMgeo [20], a detailed model of generic spatio-temporal topology and geometric description; parts of CRMsci [21], a model for scientific observation, measurements and processed data in descriptive and empirical sciences (such as biology, geology, geography, cultural heritage conservation, etc.) and of CRMarcheo [22], a model currently under development for the documentation of archaeological excavations. The CRMba follows the same principles of the CIDOC CRM model, rendering the semantics of the buildings' subclass components as properties between two classes.

■ 14
Gian Pietro Brogiolo, Archeologia dell'edilizia storica, Como 1988.

■ 15
Roberto Parenti, Archeologia dell'architettura, in: Dizionario di Archeologia. Temi, concetti e metodi, 2009, p. 39–43.

■ 16
Manfred Schuller, Building Archaeology. Icomos, Munich 2002.

■ 17
Richard Morriss, The Archaeology of Buildings, Stroud 2004.

■ 18
Martin Davies, The archaeology of standing structures, in: Australian Journal of Historical Archaeology 5, 1987, p. 54–64.

■ 19
Paola Ronzino, Nicola Amico, Franco Niccolucci, Assessment and comparison of metadata schemas for architectural heritage, in: CIPA Symposium, Prague 2011, http://www.conferencepartners.cz/cipa/proceedings/index.htm.

■ 20
Martin Doerr, Gerald Hiebel, CRMgeo: Linking the CIDOC CRM to GeoSPARQL through a spatiotemporal refinement, Technical Report: ICS-FORTH / TR-435, 2013, http://www.ics.forth.gr/isl/CRMext/CRMgeo/docs/TR435-CRM-geo.pdf.

■ 21
CRMsci: the Scientific Observation Model, http://www.ics.forth.gr/isl/CRMext/CRMsci/docs/CRMsci1.2.3.pdf.

■ 22
CRMarchaeo, http://www.ics.forth.gr/isl/CRMext/CRMarchaeo/docs/CRMarchaeo_v1.4.pdf.

Q.3 Definition of classes and properties in CRMba

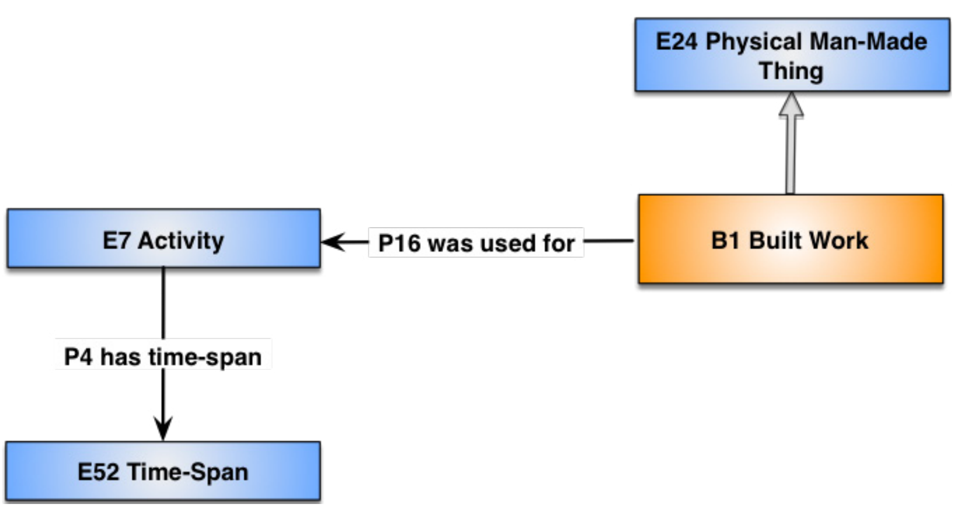
The new concepts introduced by CRMba are aimed at representing archaeological standing buildings and at defining the relations between each of their components and their relation to the whole building. The naming convention used for CRMba classes and properties follows the same principle adopted by CIDOC CRM and its extensions. In particular, classes of CRMba are identified by numbers preceded by the letter **B** and are named using noun phrases with initial capitals, while properties are identified by numbers preceded by the letter **BP** and are named in both directions using verbal phrases in lower case.

The main class introduced in CRMba is B1 Built Work, a subclass of **E24 Physical Man-Made** Thing. A B1, as described in the notes of the Art & Architecture Thesaurus (AAT) of the Getty Institute for the term Built Works, includes

> »...freestanding buildings, components of buildings, complexes of buildings, other structures, or a man-made environment, typically large enough for humans to enter, serving a practical purpose, being relatively permanent and stable...«. [23]

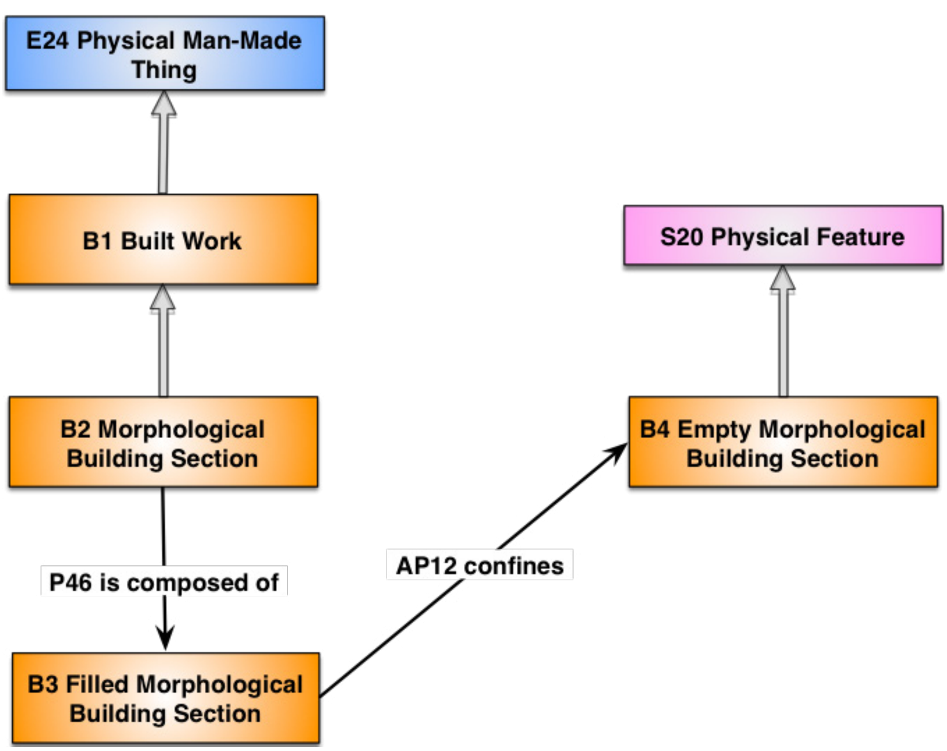
■ 23
Art & Architecture Thesaurus, AAT, http://www.getty.edu/vow/AATFullDisplay?find=built+work&logic=AND&note=&english=N&prev_page=1&subjectid=300265418.

The B1 is produced by a **E12 Production** and its temporal confinement is described by a **E52 Time-Span.** Whatever purpose the building may have been used for during the various phases of its life, this can be modelled with the property P16 was used for, which links the building with an activity (E7) 01.



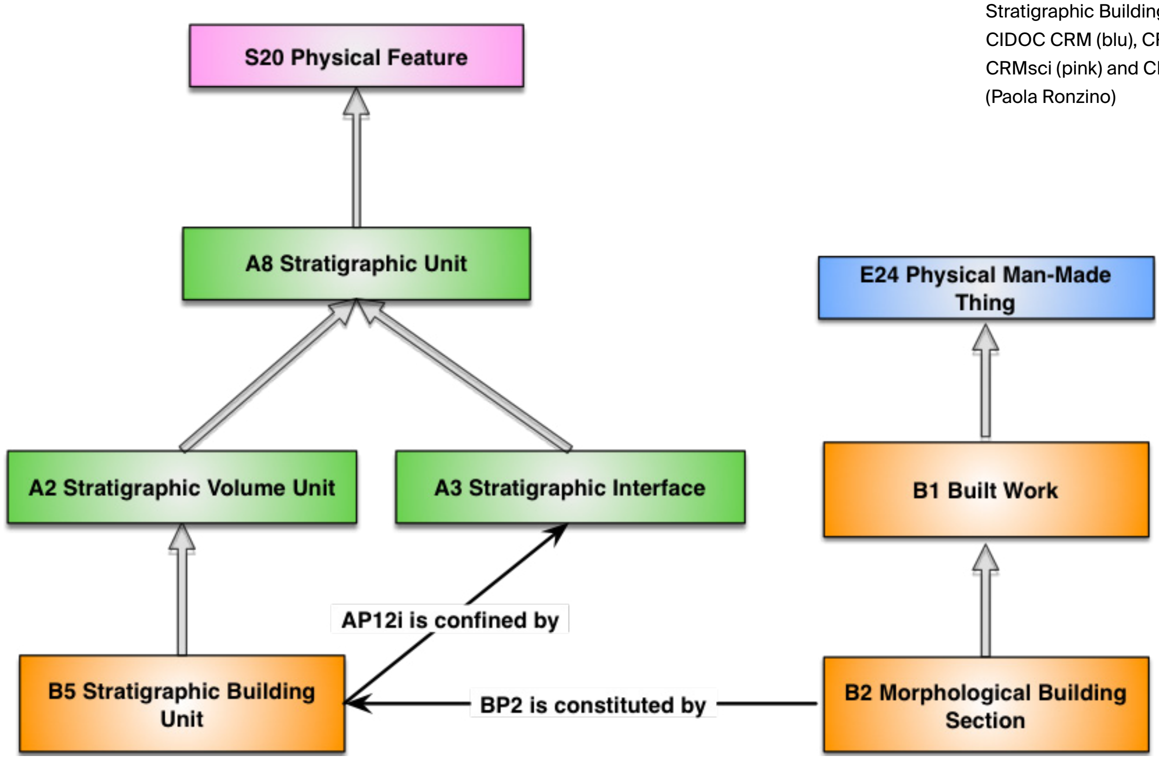
☐ 01
Use of the building modelled with CIDOC CRM (blu) and CRMba (orange) (Paola Ronzino)

B1 Built Work can be broken down into components, represented by the class **B2 Morphological Building Section.** B2 is a subclass of B1, being a specification of the class **built work.** At the same time any instances of B2 are instances of the B1 class. B2 is characterized by the fact that any instance must be a functional element for the whole building, e. g. wall, story, roof, foundations, room, etc., having a specific role within the building. A **B2 Morphological Building Section** has a duration in time and is composed of (P46) parts that are completely filled with matter, which are modelled with the class **B3 Filled Morphological Building Section.** The intentional disposition in the space of filled parts (like bricks, walls, columns, wooden panels, etc.) defines portions of space that are completely void, e. g. the opening in the wall for a doorway, or an intercolumniation and so forth. In CRMba the void parts are identified with the class **B4 Empty Morphological Building Section**, a subclass of **E26 Physical Feature.** In the particular case of a window or a doorway, respectively, the pane or the door are considered as **E18 Physical Thing** attached to them. A **B4 Empty Morphological Building Section** is linked with a **B3 Filled Morphological Building Section** through the property of CRMarchaeo **AP12 confines** 02.



☐ 02
Graph showing the building's parts modelled with CIDOC CRM (blu), CRMba (orange) and CRMsci (pink) (Paola Ronzino)

One fundamental class introduced in CRMba, explicitly devised to describe the minimal construction unit of a built structure, is the **B5 Stratigraphic Building Unit.** B5 is subclass of the CRMarchaeo **A2 Stratigraphic Volume Unit** as it refers to material entities only. The Stratigraphic Building Unit (B5) represents a single evidence of human activity intentionally performed on the building: e. g. the presence of mortar, vestments or any of the discontinuities of matter visible on a wall surface. The **B5 Stratigraphic Building Unit** is a constituent part of a **B3 Filled Morphological Building Section.** The constituency of a Stratigraphic Building Unit (B5) may be seen as a subclass of **E2 Temporal Entity** with a duration in time (P4 has time span). 02 The term constituency is used within the model with the meaning of being a costituent part. The possibility of defining the class **Constituency** is still under consideration. 03

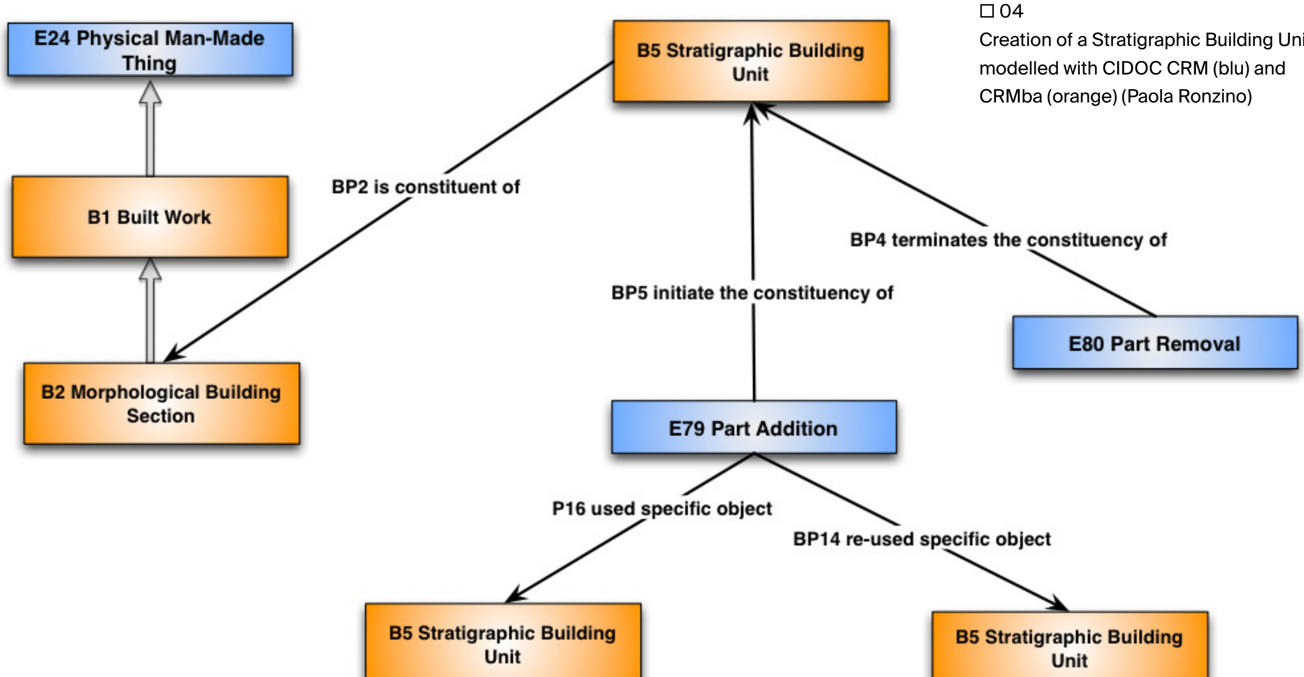


☐ 03
Graph showing the constituency of Stratigraphic Building Unit modelled with CIDOC CRM (blu), CRMba (orange), CRMsci (pink) and CRMarchaeo (green) (Paola Ronzino)

Creation of a stratigraphic building unit

The stratification genesis of subsurface deposits can be caused by natural or human actions, while the physical genesis of a stratigraphic unit in a built structure is the result of an intentional action of the creator and is described with the CRM class **E11 Modification.** Similarly to the unconsolidated soil, which can be disturbed by later intrusions or by human activities, standing structure stratigraphy may undergo modification through the ages. The modification of an archaeological deposit in built structures, which may include addition or removal of matter, are regarded as modification of the status **being part of** (i. e. the constituency) a portion of a structure within the whole **B2 Morphological Building Section.** The modification is modelled using the CRM classes **E11 Modification**, superclass of **E79 Part Addition** and **E80 Part Removal.** 04 The opening of a breach for the construction of a new window in an existing wall, for example, implies the removal of substance (E80) and consequently the addition of other substance (E79). Being part of a building is therefore expressed with the properties BP4 terminates the constituency of and BP5 initiates the constituency of, which respectively express that a **E11 Modification** event caused the status of being part of a whole.

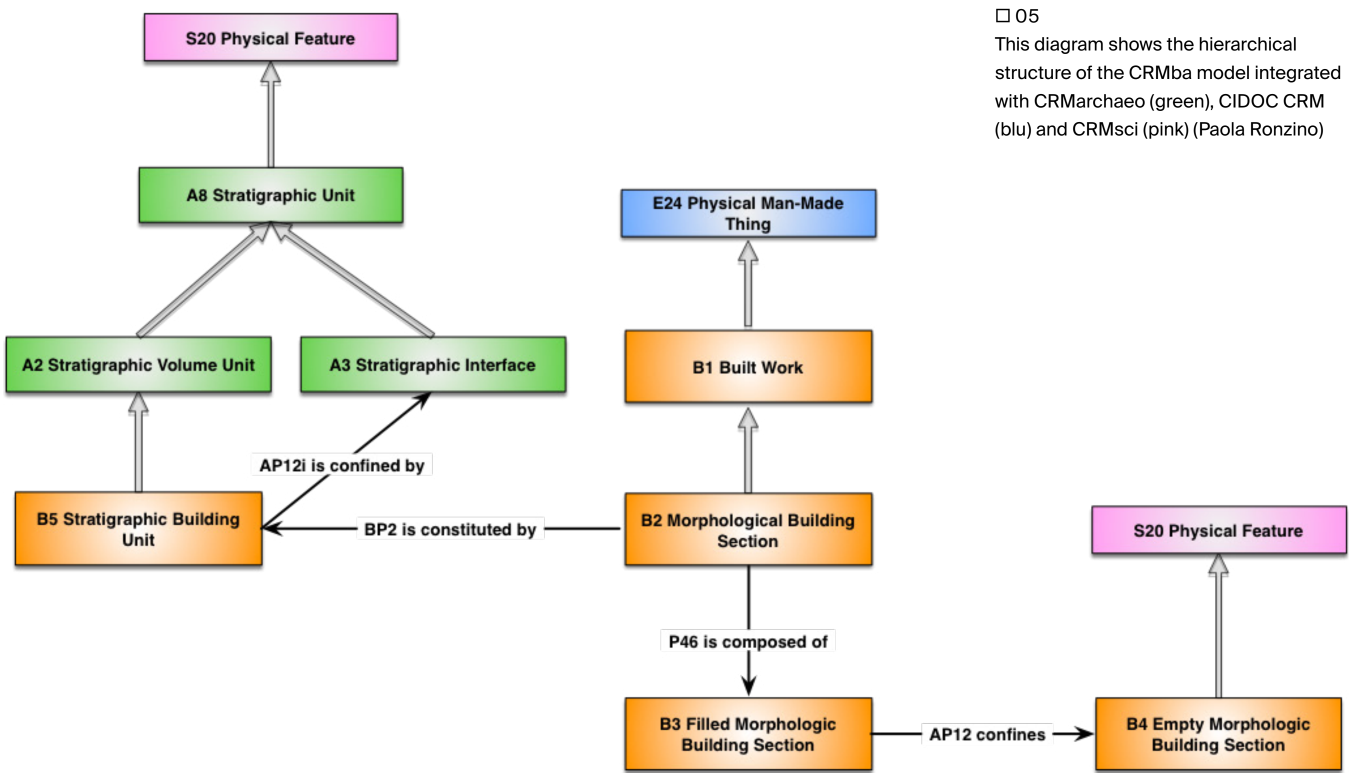
According to the objects used for the creation of new constituencies, CRMba introduces the following properties: **BP13 used specific object** and **BP14 re-used a specific object.** In the first case the object used in the construction of a new wall, for example, can be a feature made in situ, like a breach made in a wall for the opening of a new window, or a pre-constructed feature like a column. In the second case B14 is used when, for example, a decorated stone from another building is reused into the masonry of a new one. 04



☐ 04
Creation of a Stratigraphic Building Unit modelled with CIDOC CRM (blu) and CRMba (orange) (Paola Ronzino)

The stratigraphic interface

In the study of standing structures, the analysis of standing stratification turns around the concept of the stratigraphic interface, which represents a stratigraphic unit in its own right and comprises coherent parts of the boundary surface of a stratigraphic unit, as resulting from a common genesis event or process. A stratigraphic interface is a means to associate chronology and continuity to a Stratigraphic Building Unit (B5) or to a Morphological Building Section (B2) and is part of the identity and evidence of the process. The removal of existing stratification and the creation of new substances, for example, defines a stratigraphic interface, which is identified with the CRMarchaeo class **A3 Stratigraphic Interface**, subclass of **A8 Stratigraphic Unit.** A3 may be related with the **B5 Stratigraphic Building Unit** through the property **AP12 confines.** Figure 6 shows the complete CMRba model, hierarchically integrated with CRMarchaeo, CRMsci and classes CRM core. 05



☐ 05
This diagram shows the hierarchical structure of the CRMba model integrated with CRMarchaeo (green), CIDOC CRM (blu) and CRMsci (pink) (Paola Ronzino)

Q.4 Topological relations

In the analysis of archaeological buildings, the topological relations [24] can be used to study the hierarchical distribution of spaces and connections, and to perform comparative analysis of theoretical models or observed patterns (ritual, symbolic or cultural type of building). [25] In the case of buildings reduced to ruins, through the evaluation of connections between the walls and the living spaces, the process of reconstructing the original passages can be performed, thus allowing detection of anomalies like, for instance, traces pertaining to structures that are no longer there. [26] One of the most interesting features provided by the model is the possibility to build complex reasoning by means of specific classes and properties that can be interpreted, for instance, to create a system capable of formulating interpretative hypotheses. A typical example is represented by the possibility to define connectivity relationships between different environments, analysing the ways they can be interconnected. It is possible, for example, to say that two rooms are connected and to define also the entity through which this connection is made possible.

The property **BP11 is connected to** allows, for example, to establish a connection between two rooms (i. e. the empty spaces surrounded by walls) and to specify that this connection is established through a specific doorway (expressed by CIDOC CRM as **E26 Physical Feature**). BP11 identifies the instance of **B4 Empty Morphological Building Section** which is connected to another instance of B4. The instance of **E24 Physical Man Made Thing** through which the connection between the two instances of **B4 Empty Morphological Building Section** is made, can be recorded using the property **BP11.2 is connected through.** The way in which empty spaces are connected also makes explicit the transitivity connection type, expressed with the property **BP11.1 in the mode of**, using the **E55 Type** entity to describe how the passage from one environment to another happened. Transitivity through different places, can thus be automatically deduced by an inferential engine, which will be able to calculate routes between spaces that are also distant from each other, by defining a coherent path through doorways and other openings.

■ 24
Giancarlo Guizzardi, The problem of transitivity of part-whole relations in conceptual modeling revisited, in: International Conference on Advanced Information Systems Engineering (CAiSE), Amsterdam 2009.

■ 25
Gian Pietro Brogiolo, Dall'archeologia dell'architettura all'archeologia della complessità, in: Pyranae 1(38) 1997, p. 7–38 and Maurizio Cattani, Andrea Fiorini, Topologia: identificazione, significato e valenza nella ricerca archeologica, in Archeologia e Calcolatori 15, 2004, p. 317–340.

■ 26
Maura Medri, Manuale di rilievo archeologico, Laterza, Bari 2003.

Q.5 CRMba integrating with CRMarchaeo

Declaring group of activities

The identification of each homogeneous stratum on a built structure or in a sequence of subsurface deposits is the first activity of an archaeologist involved in an excavation campaign. This process aims to observe and record the nature of the various deposit units, trying to understand the phenomena involved in the formation of the deposit and its transformation in time; each stratigraphic layer and each object found is documented with the attribution of a Stratigraphic Unit (SU) identifier regardless of its nature. Most of the time, built structures found in stratigraphic excavations, are fragmentary and dispersed. This situation makes the reconstruction of the original relationships among walls, layers and artefacts quite incomprehensible and, if not properly recorded, it also makes the reconstruction of the real appearance of the built structure impossible. Further interpretative analyses of the observed entities may lead to the identification of stratigraphic units of the same nature, which may result in the assignment of common attributes.

CRMarchaeo encodes this interpretation process with the **A6 Group Declaration Event** class, subclass of **E13 Attribute Assignment**, which can be used to state that a set of items is intended to be part of one physical thing. A grouping activity of this kind can occur in the presence of artefacts embedded in certain deposits, for instance, a capital or other architectural elements that are found buried in a fragmentary way (e. g. two pieces of wall are recognized to be part of the same built structure). As first step, an archaeologist assigns an ID to each identified SU. This attribution can be encoded by using the **A2 Stratigraphic Volume Unit** class of CRMarchaeo. During the interpretation phase, the archaeologist, supported by the identification of common attributes may infer on the intention behind the production of a group of items. This interpretation can be encoded with the **A6 Group Declaration Event**. The items identified as **intentionally-built** structure can be assigned a new identifier and encoded with the **B5 Stratigraphic Building Unit.** [27] When possible, this approach may be extended to create hierarchical relationships among the components of the building and the whole structure, from the description of single architectural elements (B5) to functional units (B2), to a more articulated buried built work or built complex (B1).

■ 27
Paola Ronzino, Harmonizing the CRMba and CRMarchaeo models, in: International Journal on Digital Libraries, 18 (4) 2017, pp. 253–261.

This approach allows to keep track of the reasoning process of an archaeologist by archiving both the raw data (e. g. the attribution of IDs to the stratigraphic units) and the information derived by the inferences made during the interpretation process of the various stratigraphic units in order to make further interpretations possible.

Embedded built structures into a stratigraphic

Artefacts that are found embedded in a stratigraphic unit of an archaeological deposit are modelled with the CRM class **E18 Physical Thing**, superclass of Stratigraphic Units (A8) and are related to the **A7 Embedding** through the CRMarchaeo property **AP18 is embedded.** The **embedding** is a state of an instance of E18 being partially or completely embedded in a particular position, with relative stability in one or more A2 Stratigraphic Volume Unit. [28] Artefacts that are incorporated in a wall of a standing building are more specifically regarded in CRMba as B5 Stratigraphic Building Unit, subclass of **A2 Stratigraphic Volume Unit.** In this case, the physical relationships of an artefact with its **container** (e. g. the wall) is expressed with the concept of **being part of** connecting **B5 Stratigraphic Building Unit** and **B2 Morphological Building Section** with the property **BP2 is or was constituent of.** This reveals the intentional use of the object as a functional part of the wall, unlike in the case of an archaeological deposit where the embedding concept may underline the fortuity of an artefact being buried in a certain deposit due to natural or human activities. The discovery of an architectural element, e. g. a capital, within a clay stratus will be encoded linking the **E18 Physical Thing** and the **A2 Stratigraphic**

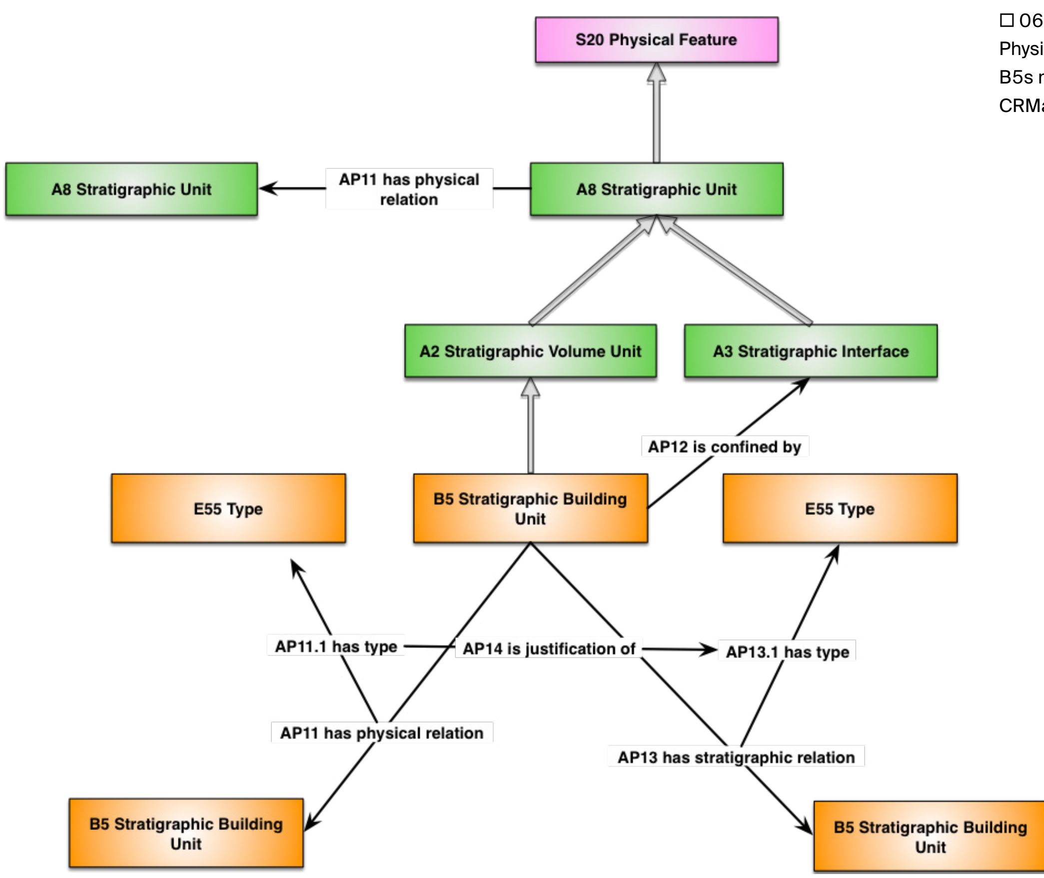
■ 28
CRMarchaeo, http://www.ics.forth.gr/isl/CRMext/CRMarchaeo/docs/CRMarchaeo_v1.4.pdf.

Volume Unit with the property **AP15 is or has remains contained in.** After the interpretation process the same object could be recognized as an architectural element and encoded as **B5 Stratigraphic Building Unit** that is or was constituent (BP2) of **B2 Morphological Building Section.**

Physical and stratigraphic relations

The stratigraphic sequence observed in an archaeological site or in a standing structure, represents its modification through time, while the stratigraphic unit represents one event in time. Each Stratigraphic Building Unit (B5) may have physical and stratigraphic relationships with one or more stratigraphic units. The physical relationships between two stratigraphic units are expressed through the CRMarchaeo class AP11 has physical relation, qualifying the possible relationships using property **AP11.1 has type (E55 Type).** The vocabulary used to describe the type of physical relationships includes: **fills**, **is filled by**, **cuts**, **is cut by**, **bound**, **is bonded by**, and so forth.

The stratigraphic relationships between two Stratigraphic Building Units (B5) are instead modelled with the CRMarchaeo property **AP13 has stratigraphic relation.** The relations expressed by AP13, namely **before**, **after** and **same as**, can be inferred from the kind of physical relations between two B5. 06



☐ 06
Physical and stratigraphic relation between B5s modelled with CRMba (orange) using CRMarchaeo properties (Paola Ronzino)

Q.6 Conclusions and further work

The outcome of this work consists in the development of the CRMba model, an extension of the CIDOC CRM ontology, for the documentation of standing buildings [01]. The extension introduces new concepts that enable to reason with the available data and to support archaeological interpretation of archaeological buildings. In particular, the physical relations of the stratigraphic units, information that is important to understand the various phases of a building, and the topological relations of functional spaces are made explicit through new properties. Furthermore, CRM_{ba} introduces the concept of use and re-use of artefacts as part of activities already included in the CIDOC CRM, such as **E11 Modification, E12 Production, E79 Part Addition, E80 Part Removal**. These concepts can support the archaeological interpretation of various activities that affected the building, by determining the beginning (BP5) and the end (BP4) of the constituency of a Stratigraphic Building Units (B5) with a Morphological Building Section (B2) and with a Built Work (B1). A first attempt to harmonize the ontological model for building archaeology documentation with the archaeological extension of the CIDOC CRM — CRMarchaeo — has been carried out [29] with good results. The CRMba model is still under improvement and cannot be considered complete. More work needs to be done, especially towards the integration of a possible class **Function.**

Further work is also currently carried out to demonstrate how the integrated use of BIM and semantic technologies permits to connect different data sources and combine them into a semantic network that allows to have a unique representation of the building and its context.

A summary of the undergoing activities follows below.

Function

As described above, B2 comprises instances of man-made things that are considered functional units for the whole building (e. g. rooms, foundations, roof, and so forth).

From the analyses of the metadata schemas and standards for the documentation of built heritage, four main functional aspects have been identified.

The functional roles of the **parts of the building** may be expressed as types of a class **B6 Function** (still under discussion for approval), using the CRM class **E55 Type**, and related to **B2 Morphological Building Section** through the possible property **BP12 has function.**

The identified functional aspects concern a) statics, i. e. the ability of architectural elements to safely resist all actions a building is likely to face across time; b) affordance, borrowed from perceptual psychology [30] and used as a conceptual framework to understand the relationship between form and function of an element; c) protection, i. e. every element that provides passive protection from environmental and human activities (e. g. plaster, parapet, revetment, ceiling eaves, coating); d) decoration, i. e. something added to a building to improve its appearance (e. g. mouldings, inscriptions, mosaics, frieze etc.).

■ 29
Paola Ronzino, Harmonizing the CRMba and CRMarchaeo models, in: International Journal on Digital Libraries, Special Issue on Extending, Mapping and Focusing the CIDOC CRM 2016 https://link.springer.com/article/10.1007/s00799-016-0193-3.

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James J. Gibson, The theory of affordances, in: Robert Shaw, John Bransford (Hg.), Perceiving, Acting and Knowing, New York 1977, pp. 67–82.

Interoperability and integration of archaeological standing buildings information with BIM

Further work includes research carried out by the author of this paper aiming at investigating the use of the CIDOC CRM ontology and its archaeological extensions — CRMba and CRMarchaeo — to allow the integration of 3D models and the related information within Building Information Modelling (BIM) environments and in non-BIM native systems.

Initially used in urban areas for the description of new buildings, BIM has been extended to the field of historical architecture for purposes related to the 3D rendering and the collection of data about the heritage building (HBIM). [31] BIM applications can be used to model existing ancient buildings as well as trying to virtually reconstruct built structures that no longer exist, simulating the appearance that these structures would have had in the past, the materials which they were made of and the various phases of construction, integrating the information available on the built structure. [32]

BIM allows users to model a building not only in terms of lines and volumes, but also in terms of the semantics of its constituents. The 3D models can be viewed, navigated, queried, via semi-automatic selection processes and costumed queries, modelled on defined ontological patterns.

Ontologies, therefore, play a key role in the expression of qualified semantic relationships that underpin the link between the data, making it possible to describe the information related to cultural heritage through a series of relations, types and connections.

When one approaches the virtual reconstruction of an ancient building, the first phase of the activity includes an accurate analysis to understand how it was done, what the available sources were, what information ensures effective organization of the data.

In some cases, when possible, it is necessary to document the building with surveys, photos, sketches and measurements, and to integrate it with a study of the existing sources (drawings or plants). Therefore, the ontology that is used to describe the information is very important in the digital reconstruction of an ancient building.

In most of the BIM environments, reference is made to the ontology used by the software. The most used data model in this area is the Industry Foundation Classes (IFC), a neutral and open file format used to describe construction data and the construction industry.

■ 31
Maurice Murphy, Eugene McGovern, Sara Pavia, Historic building information modelling (HBIM), in: Structural Survey, Vol. 27/4, 2009, pp. 311–327 and Conor Dore, Maurice Murphy, Integration of Historic Building Information Modeling and 3D GIS for Recording and Managing Cultural Heritage Sites, in: VSMM Conference Virtual Systems in the Information Society, 2012, pp. 369–376.

■ 32
Simone Garagnani, Anna Maria Manferdini, Parametric accuracy: Building Information Modeling process applied to the cultural heritage preservation, in: 3DArch2013, 2013, pp. 87–92.

It is an object-based file format with a data model developed by buildingSMART [33] to facilitate interoperability between the disciplines of architecture, engineering and the construction industry. It provides a collaborative format commonly employed in projects that use BIM-based methodologies.

Many governments are imposing the use of IFC files for construction projects of public administration properties due to the model's ability to facilitate interoperability between all the software platforms that allow it. Nevertheless, when one uses a BIM process for a different scope besides new buildings, i. e. adopting it for the reconstruction of non-existing buildings or for the reconstruction of a standing historical building, the basic ontology of some software is not enough to document the information, hence the need to integrate the information using a domain ontology.

Therefore, the research carried out as further investigation of this work aims at exploring the integration of the CIDOC CRM ontology and its archaeological extensions with 3D models and the collected information. The efficacy of applying the parametric and semantics methods of three-dimensional modelling in archaeology stems from the need to create modern 3D standardized and all-encompassing databases, containing all the material relating to the same building within the scope of a large cloud-database. This will enable not only to ensure a simultaneous use of vast resources shared on the network in real time, but it also allows the comparison of data from disparate sources and, therefore, the qualitative increase of statistics and crossed analysis.

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buildingSMART, http://buildingsmart.org/standards/standards-library-tools-services/#standards.